

CLAIMS

What is claimed is:

1. A method for operating an orthogonal frequency duplex multiplexing (OFDM) communications system, comprising:

when transmitting data over a plurality of OFDM sub-channels from an OFDM transmitter to an OFDM receiver through a channel,

operating an adaptive learning automaton to adjust values of modulation coding scheme (MCS) switching thresholds so as to maximize at least one selected performance criterion;

based on the values of the switching thresholds, selecting a MCS and modulating data with the selected MCS; and

transmitting the modulated data over at least some of the sub-channels.

2. A method as in claim 1, further comprising:

receiving the data at the OFDM receiver; and

demodulating the received data using a demodulator that corresponds to the selected MCS.

3. A method as in claim 2, where the automaton is located at the OFDM transmitter, and where feedback information that is indicative of the at least one selected performance criterion is signaled from the OFDM receiver to the OFDM transmitter, and where information indicative of the selected MCS is signaled from the OFDM transmitter to the OFDM receiver.

4. A method as in claim 2, where the automaton is located at the OFDM receiver, and where information that is indicative of the selected MCS is signaled from the OFDM receiver to the OFDM transmitter.

5. A method as in claim 1, where the selected performance criterion comprises data throughput.

6. A method as in claim 1, where the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM symbol.

7. A method as in claim 1, where the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is spread across a plurality of OFDM symbols.

8. A method as in claim 1, further comprising a step of initializing the automaton by:

partitioning the switching thresholds into a pre-defined set of combinations to cover all or substantially all of a range of operating signal-to-noise ratios (SNRs);

initializing an internal probability vector of the automaton such that the probabilities of choosing a particular action are the same;

mapping each particular action to a unique switching threshold combination; and

selecting an action at random.

9. A method as in claim 8, where for a mode 1 operation where the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM symbol, further comprising:

based on selected switching threshold values, determining what MCS to use in each of the sub-carriers, thereby determining how many data packets an OFDM symbol can carry;

loading the sub-carriers with the data packets;

transmitting the OFDM symbol from the OFDM transmitter;

receiving the OFDM symbol at the OFDM receiver and determining a packet error rate (PER) to determine data throughput (TP), $TP = (1 - PER) * PPS$, where PPS = packets-per-symbol;

based on the data throughput, updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values;

selecting another action at random using the updated automaton internal probability vector; and

at the next OFDM symbol, assigning MCSs to the sub-carriers according to the updated switching threshold values, loading new data packets to the sub-carriers accordingly, and transmitting the next OFDM symbol.

10. A method as in claim 8, where for a mode 2 operation where the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is spread across a plurality of OFDM symbols, further comprising:

based on selected switching threshold values, determining what MCS to use in each of the sub-carriers, and loading each sub-carrier with a symbol from an assigned data packet;

transmitting a frame of OFDM symbols from the OFDM transmitter;

receiving the frame of OFDM symbols at the OFDM receiver and determining a packet error rate (PER) to determine data throughput (TP), $TP = (1 - PER) * PPF$, where PPF = packets-per-frame, or $TP = (1 - PER) * PPS$, where PPS = packets-per-symbol;

based on the data throughput, updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values;

selecting another action at random using the updated automaton internal probability vector; and

at the first OFDM symbol of the next frame, assigning MCSs to the sub-carriers according to the updated switching threshold values, loading a new frame of data packets to the sub-carriers accordingly, and transmitting the next frame of OFDM symbols.

11. A method as in claim 9, where loading the sub-channels further comprises disabling a sub-channel and not loading a data packet if the sub-channel condition is poor.

12. A method as in claim 10, where loading the sub-channels further comprises disabling a sub-channel and not loading a data packet if the sub-channel condition is poor.

13. A method as in claim 9, where one automaton learning trial is performed per OFDM symbol.

14. A method as in claim 10, where one automaton learning trial is performed per OFDM frame.

15. A method as in claim 8, where for a mode 1 operation where the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM

symbol, further comprising:

based on selected switching threshold values, determining what MCS to use in each of the sub-carriers, thereby determining how many data packets an OFDM symbol can carry;

loading the sub-carriers with the data packets;

receiving the OFDM symbol at the OFDM receiver and determining a packet error rate (PER) to determine data throughput (TP) in accordance with:

$TP = (1 - PER) * PPS$, where PPS = packet-per-symbol;

based on the average TP, updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values, where the automaton internal probability vector is updated for each packet received in an OFDM symbol;

selecting another action at random using the updated automaton internal probability vector; and

at the next OFDM symbol, assigning MCSs to the sub-carriers according to the updated switching threshold values, loading new data packets to the sub-carriers accordingly, and transmitting the next OFDM symbol.

16. A method as in claim 8, where for a mode 2 operation where the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is spread across a plurality of OFDM symbols, further comprising:

based on selected switching threshold values, determining what MCS to use in each of the sub-carriers, and loading each sub-carrier with a symbol from an assigned data packet;

transmitting a frame of OFDM symbols from the OFDM transmitter;

receiving the frame of OFDM symbols at the OFDM receiver and determining a packet error rate (PER) to determine data throughput (TP), where the PER and TP are determined only for those packets (active packets) in an active SNR region defined as a SNR range covered by the available combinations of switching thresholds, and where PER and TP are determined in accordance with:

$TP = (1 - PER) * PPF$, where PPF = packets-per-frame, or $TP = (1 - PER) * PPS$, where PPS = packets-per-symbol;

based on the averaged data throughput for active packets only, updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values, where the automaton internal probability vector is updated for each active packet received in a OFDM frame;

selecting another action at random using the updated automaton internal probability vector; and

at the first OFDM symbol of the next frame, assigning MCSs to the sub-carriers according to the updated switching threshold values, loading a new frame of data packets to the sub-carriers accordingly, and transmitting the next frame of OFDM symbols.

17. An orthogonal frequency duplex multiplexing (OFDM) communications system, comprising:

an OFDM transmitter for transmitting data over a plurality of OFDM sub-channels, said OFDM transmitter comprising a plurality of modulators of different types;

an OFDM receiver for receiving the data from the plurality of OFDM sub-channels, said

OFDM receiver comprising a plurality of corresponding demodulators of the different types; and

an adaptive learning automaton for adjusting values of modulation coding scheme (MCS) switching thresholds so as to maximize at least one selected performance criterion, said OFDM transmitter being responsive to the MCS switching thresholds for selecting an appropriate one or ones of said modulators for modulating the data for various ones of the sub-channels.

18. An OFDM communications system as in claim 17, where said OFDM receiver demodulates the received data using one or more demodulators that correspond to the selected modulators.

19. An OFDM communications system as in claim 18, where the automaton is located at the OFDM transmitter, and where feedback information that is indicative of the at least one selected performance criterion is signaled from the OFDM receiver to the OFDM transmitter, and where information indicative of the selected MCS is signaled from the OFDM transmitter to the OFDM receiver.

20. An OFDM communications system as in claim 18, where the automaton is located at the OFDM receiver, and where information that is indicative of the selected MCS is signaled from the OFDM receiver to the OFDM transmitter.

21. An OFDM communications system as in claim 17, where the selected performance criterion comprises data throughput.

22. An OFDM communications system as in claim 17, where the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM symbol.

23. An OFDM communications system as in claim 17, where the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is

spread across a plurality of OFDM symbols.

24. An OFDM communications system as in claim 17, further comprising means for initializing the automaton by partitioning the switching thresholds into a pre-defined set of combinations to cover all or substantially all of a range of operating signal-to-noise ratios (SNRs); initializing an internal probability vector of the automaton such that the probabilities of choosing a particular action are the same; mapping each particular action to a unique switching threshold combination; and selecting an action at random.

25. An OFDM communications system as in claim 24, where for a mode 1 operation the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM symbol, and further comprising means, responsive to selected switching threshold values, for determining what MCS to use in each of the sub-carriers, thereby determining how many data packets an OFDM symbol can carry; for loading the sub-carriers with the data packets; for transmitting the OFDM symbol from the OFDM transmitter; for receiving the OFDM symbol at the OFDM receiver and determining a packet error rate (PER) to determine data throughput; and means, responsive to the determined data throughput, for updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values, and for selecting another action at random using the updated automaton internal probability vector and, at the next OFDM symbol, assigning MCSs to the sub-carriers according to the updated switching threshold values, loading new data packets to the sub-carriers accordingly, and transmitting the next OFDM symbol.

26. An OFDM communications system as in claim 24, where for a mode 2 operation the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is spread across a plurality of OFDM symbols, and further comprising means, responsive to selected switching threshold values, for determining what MCS to use in each of the sub-carriers, and loading each sub-carrier with a symbol from an assigned data packet; for transmitting a frame of OFDM symbols from the

OFDM transmitter; for receiving the frame of OFDM symbols at the OFDM receiver and determining a packet error rate (PER) to determine data throughput; and means, responsive to the determined data throughput, for updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values; for selecting another action at random using the updated automaton internal probability vector and, at the first OFDM symbol of the next frame, for assigning MCSs to the sub-carriers according to the updated switching threshold values, loading a new frame of data packets to the sub-carriers accordingly, and transmitting the next frame of OFDM symbols.

27. An OFDM communications system as in claim 25, where loading the sub-channels further comprises disabling a sub-channel and not loading a data packet if the sub-channel condition is poor.

28. An OFDM communications system as in claim 26, where loading the sub-channels further comprises disabling a sub-channel and not loading a data packet if the sub-channel condition is poor.

29. An OFDM communications system as in claim 25, where one automaton learning trial is performed per OFDM symbol.

30. An OFDM communications system as in claim 25, where one automaton learning trial is performed per OFDM frame.

31. An OFDM communications system as in claim 24, where for a mode 1 operation the OFDM communications system operates by loading a plurality of data packets across the plurality of sub-carriers so that the plurality of data packets are loaded into one OFDM symbol, and further comprising means, responsive to selected switching threshold values, for determining what MCS to use in each of the sub-carriers, thereby determining how many data packets an OFDM symbol can carry; for loading the sub-carriers with the data packets; for receiving the OFDM symbol at the OFDM receiver and determining a packet

error rate (PER) to determine data throughput (TP) in accordance with:

$TP = (1 - PER) * PPS$, where PPS = packets-per-symbol;

further comprising means, responsive to the average TP, for updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of the selected action is increased, thereby updating the switching threshold values, where the automaton internal probability vector is updated for each packet received in an OFDM symbol; for selecting another action at random using the updated automaton internal probability vector and, at the next OFDM symbol, for assigning MCSs to the sub-carriers according to the updated switching threshold values, loading new data packets to the sub-carriers accordingly, and transmitting the next OFDM symbol.

32. An OFDM communications system as in claim 24, where for a mode 2 operation the OFDM communications system operates by loading each sub-carrier with a data packet so that each data packet is spread across a plurality of OFDM symbols, and further comprising means, responsive to selected switching threshold values, for determining what MCS to use in each of the sub-carriers, and loading each sub-carrier with a symbol from an assigned data packet; for transmitting a frame of OFDM symbols from the OFDM transmitter; for receiving the frame of OFDM symbols at the OFDM receiver and determining a packet error rate (PER) to determine data throughput (TP), where the PER and TP are determined only for those packets (active packets) in an active SNR region defined as a SNR range covered by the available combinations of switching thresholds, and where PER and TP are determined in accordance with:

$TP = (1 - PER) * PPF$, where PPF = packets-per-frame, or $TP = (1 - PER) * PPS$, where PPS = packets-per-symbol;

further comprising means, responsive to the averaged data throughput for active packets only, for updating the internal probability vector of the automaton such that only if the selected action has resulted in good throughput performance the selection probability of

the selected action is increased, thereby updating the switching threshold values, where the automaton internal probability vector is updated for each active packet received in an OFDM frame; for selecting another action at random using the updated automaton internal probability vector and, at the first OFDM symbol of the next frame, for assigning MCSs to the sub-carriers according to the updated switching threshold values, loading a new frame of data packets to the sub-carriers accordingly, and transmitting the next frame of OFDM symbols.